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High resolution isentropic model applied to local weather forecasting

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To our dear friend, mr. sc. Dražen Glasnović who was an exceptional research scientist. He left too soon taking his great ideas with him. Nevertheless, his priceless work will keep us going and he will never be forgotten.

This paper is primarily devoted to general discussion of HRID (High resolution isentropic diagnosis) model developed by Glasnović (1983) and its vertical time cross-sections used operationally on direct output of forecasting model ALADIN (Aire Limitee Adaptation Dynamique et Development International). HRID is based on polynomial hydrostatic adjustment technique making use of reciprocal value of thermal stability parameter and its higher order derivatives. Since these relations are applied in local points of vertical interpolation, the problem is considered analytically, eliminating the finite difference approximation procedure in layers with different isentropic thicknesses. This paper presents a local 72 hourly ALADIN/HRID forecast for the city of Split, Croatia, at the eastern Adriatic coast, with detailed vertical atmospheric structure indicating the characteristic features of a frontal passage on 2 January 2007.

Keywords: ALADIN, HRID, objective analysis, vertical cross-sections

1. Introduction

Almost 60 years ago Cressman (1950) introduced a definition of objective analysis in meteorology as the procedure of transforming data from irregularly spaced stations to regularly spaced grids. Since that time, a great number of objective methods were developed and applied in construction of numerical analysis and forecasting. A great success in the development of objective analysis technique was achieved by Shapiro and Hastings (1973) using Hermite polynomial interpolation scheme between sounding stations, to construct isentropic objective analysis. They successfully applied this technique in the horizontal, but their cubic polynomials resulted in numerous superadiabatic layers, which were not present in the original data. Instead they used final difference approximation which was also used by Wittaker and Petersen (1977) in isentropic analysis applying second order Lagrangian polynomials. In spite of this they emphasised the advantage of isentropic analysis in comparison with height or pressure coordinates. A similar approach was retained by Čapka (1980) for the explanation of a non-developing cyclogenesis in the gulf of Genoa.

Unlike these attempts Glasnović (1978) was the first who successfully applied vertical interpolation in isentropic system including a polynomial hydrostatic adjustment technique (PHAT) based on the reciprocal of the thermal stability parameter and its derivatives of a higher order. Such an approach was used by Glasnović and Jurčec (1990) to define the method for Bora layer determination.

In this paper we describe the construction and operational usage of high resolution time cross-sections whose very first version was developed in 1994 when Croatia joined the international project ALADIN in Météo France (Brzović and Glasnović, 1997). The model was adapted to Central Europe within the frame of the regional centre LACE (Limited area central Europe). The first application of ALADIN/LACE prognostic model had grid size of 10.6 km, with 24 vertical levels and prognostic time interval of 48 hours (Bubnova et al., 1995). In this paper an updated version of ALADIN/HRID local forecast with prognostic period extended to 72 hours operational in Meteorological and Hydrological Service since 2006 is presented.

2. The polynomial hydrostatic adjustment technique

To improve the description of atmospheric fields in the vertical Glasnović simulated the first successful analysis of cross-sections using the soundings data (1990). The key element in this work was the development of the polynomial hydrostatic adjustment technique (PHAT) introduced to replace conventional finite difference approximation while incorporating the physics of the finest atmospheric processes into the analysis. In the case where observational or different sources of information are input to the analysis tool, systematic errors can be reduced.

In isentropic coordinate system it was necessary to compute the derivatives of pressure as a function of potential temperature. Suitable relations are derived (Glasnović, 1983) from the isentropic hydrostatic equation

$$\frac{\partial M}{\partial \theta} = \varepsilon \tag{1}$$

where M is the Montgomery potential, defined by the relation

$$M = \varepsilon\theta + \varphi \tag{2}$$

and ε Exner function

$$\varepsilon = c_p \left(\frac{p}{p_0} \right)^k \qquad (3)$$

with $k = \dfrac{R}{c_p}$. ϕ is geopotential, R is a gas constant for air and c_p is specific heat at constant pressure for a moist atmospheric gas mixture.

PHAT offers a possibility of calculation of, not only the first, but also of higher order derivatives of pressure as a function of potential temperature in the relation of the reciprocal value of thermal stability as

$$\frac{\partial p}{\partial \theta} = -\frac{1}{k}\frac{p}{\theta} \qquad (4)$$

derived by Glasnović (1983). Relation (4) shows that for the calculation of pressure changes with potential temperature, it is not necessary to use approximations in finite differences.

Although this technique is strictly hydrostatic due to the mathematical localization it can be successfully applied in a nonhydrostatic atmosphere. It is also shown that PHAT offers the possibility of a transition from the isentropic into any other suitable coordinate system without the assumption on vertical stability.

Selecting z as vertical coordinate an alternative form of the isentropic hydrostatic equation is obtained as

$$\frac{\partial z}{\partial \theta} = \frac{\varepsilon}{g} = \frac{c_p}{g} \left(\frac{p}{p_0} \right)^k \qquad (5)$$

Thus, PHAT enables a more economical vertical initialization, and avoids any kind of averaging during the calculation, ensuring a better implementation of lower scale processes including the neighbourhood of a point.

3. The vertical time cross-sections constructed on the output of numerical model ALADIN

Although HRID was initially designed as a diagnostic model it found its best and most useful application in local weather forecasting, applied on vertical time cross-sections. These vertical cross-sections are constructed on the output data of prognostic meso-scale forecast model ALADIN referred to as pseudotemps (Brzović and Glasnović, 1997).

ALADIN (Aire Limitee Adaptation Dynamique developement InterNational) is a limited area model based on global models ARPEGE (Action de Recherche Petite Echelle Grande Echelle) and IFS (Integrated Forecast System). It uses spectral representation of model fields in 37 hybrid vertical levels (Simmons and Burridge, 1981), whose density decreases from the surface to the top of the troposphere. Vertical integration is done in finite differences. The model is based on primitive prognostic equations which are resolved for the horizontal wind components, temperature, specific humidity and surface pressure. On the other hand, processes such as radiation (Geleyn and Hollingsworth, 1979; Ritter and Geleyn, 1992), vertical transport of humidity and heat (Giard and Bazile, 2000), vertical diffusion (Louis et al., 1982) and shallow convection (Geleyn, 1987) are parameterized, while convective and stratiform precipitation are taken into account separately.

The postprocessing procedure includes a number of thermodynamic parameters which characterize the vertical atmospheric structure in meso scale. Processed by the polynomial adjustment technique and described by the relations (1)–(5) the adaptation concerns thermodynamic parameters such as Brunt Vaisala frequency, Scorer parameter and Richardson number.

Figure 1 presents an example of ALADIN/HRID prognostic cross-section for Split, for 1 January 2007 12 UTC + 72 hours, calculated in isentropic and then transformed to z coordinate system. The cross-section extends to 10 kilometres in the vertical, covering most of the troposphere and enabling us to follow the passage of the cold front on 2 January shown in synoptic chart in Figure 2. The front can be easily recognized by the temperature decrease and high moisture content e.g. relative humidity during the first 30 hours.

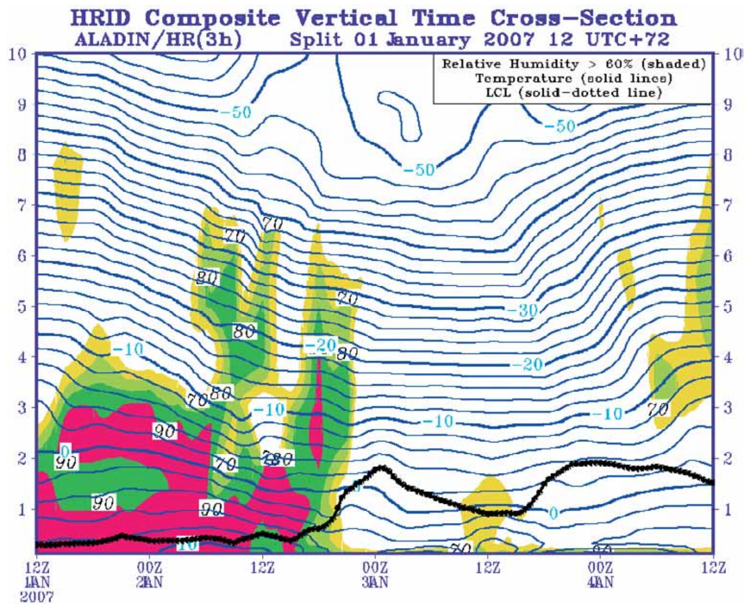

Figure 1. HRID composite vertical time cross-section, 72 hour forecast starting from 12 UTC analysis 1 January 2007, with relative humidity greater than 60 %, temperature and lifting condensation level LCL.

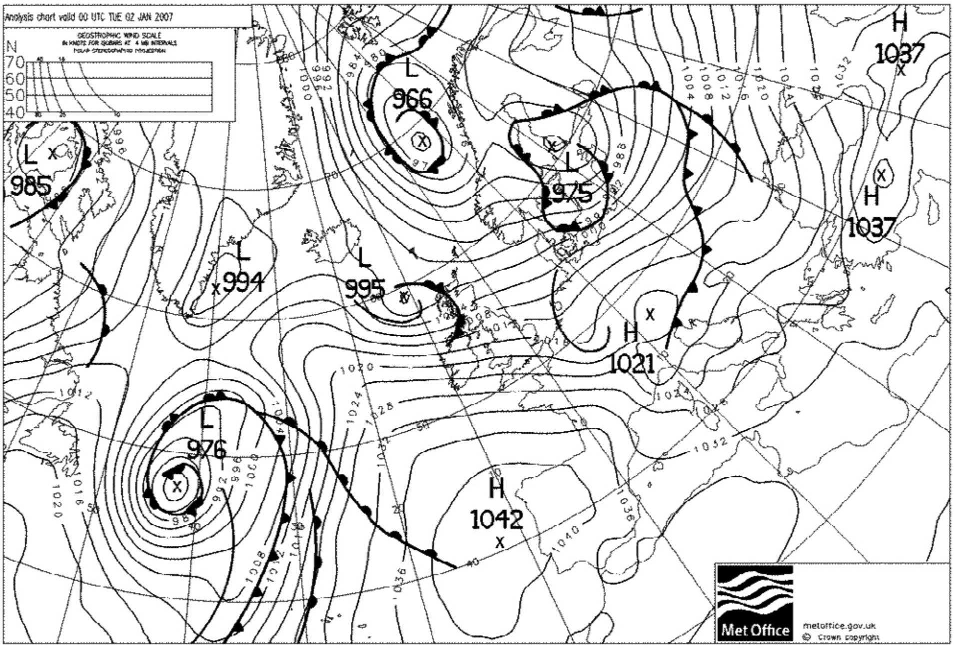

Figure 2. Surface analysis chart for 00 UTC 2 January 2007, source: http://www.wetterzentrale.de/topkarten/fsfaxbra.html

The upward extending lines of equivalent potential temperature, hereafter referred to as equipotential temperature, given by Bolton (Bolton, 1980), in Figure 3 confirm the existence of the cold front in the area of increased specific humidity. Even more, the closed circled isentropes indicate that the lower troposphere is highly unstable. Convectively unstable areas are depicted by the green shade. The temperature increase and lowering of the equipotential temperature on 4 January indicates the upper level warming.

The same features can be recognized in Figure 4 with Montgomery potential superimposed on static energy changes related to atmospheric stability (see paper by Glasnović, 1996).

The corresponding wind field is presented in Figure 5. The most striking feature of the cross-section is the westerly wind maximum in the morning of 2 January, with the Jet stream reaching down to 4.5 kilometres. With the cold front passage the wind is weakening and changing direction quite rapidly. The situation in the lower levels shows a typical frontal behaviour. The prefrontal situation is characterized by Jugo, south-easterly wind common for the Adriatic basin. With the outbreak of the cold air, in the afternoon of 2 January, the wind is changing direction to north-east and increasing abruptly suggesting the exact time when the front reached the city of Split. And finally, it is clear

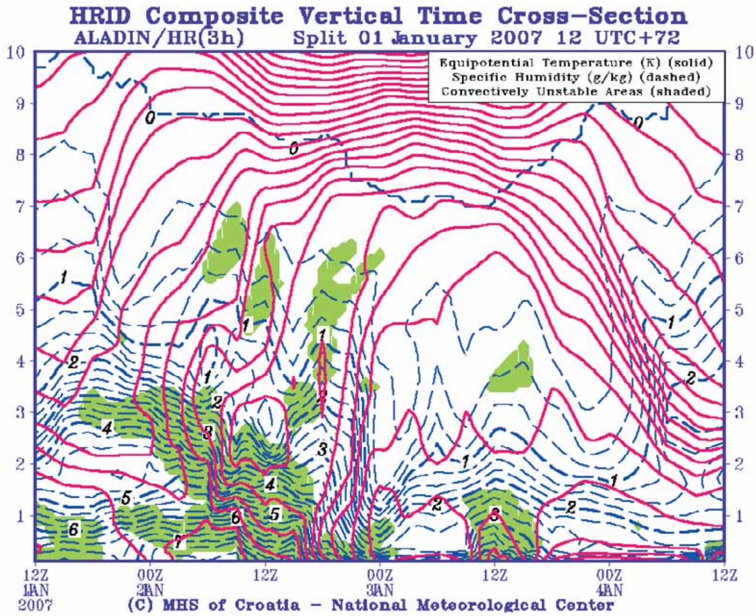

Figure 3. HRID composite vertical time cross-section, 72 hour forecast starting from 12 UTC analysis 1 January 2007 with equipotential temperature, specific humidity and convectively unstable areas

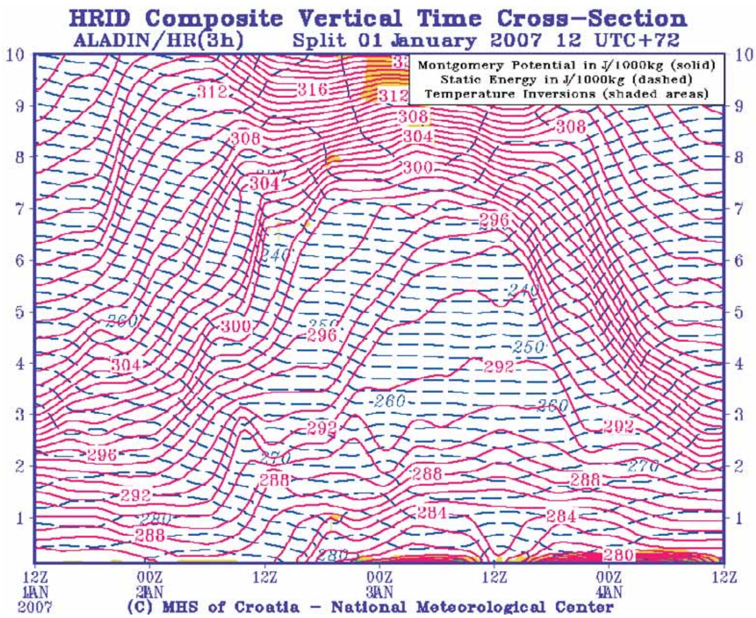

Figure 4. HRID composite vertical time cross-section, 72 hour forecast starting from 12 UTC analysis 1 January 2007 with Montgomery potential, static energy and temperature inversions.

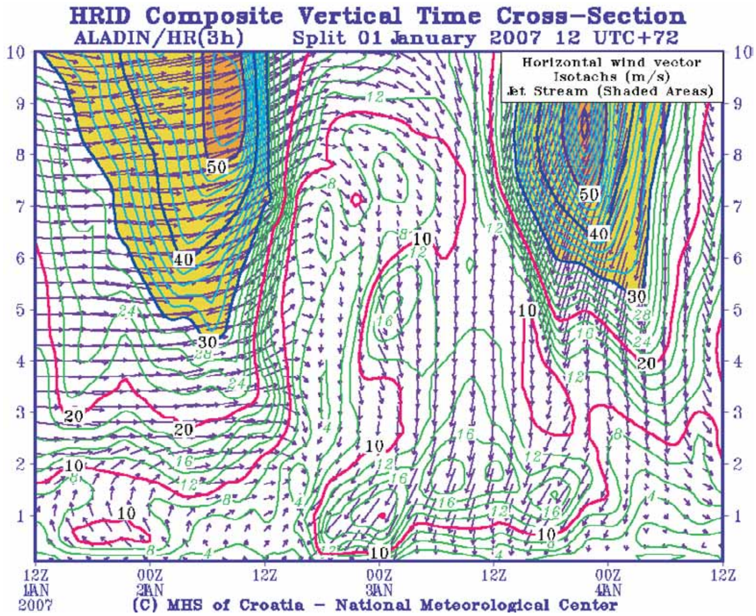

Figure 5. HRID composite vertical time cross-section, 72 hour forecast starting from 12 UTC analysis 1 January 2007, with horizontal wind vector, isotachs and jet stream.

now that the upper-level feature on 4 January is actually a nicely pronounced ridge preceded by a strong northerly Jet.

Some characteristics of the low troposphere manifested in associated weather events are shown in Figure 6. It is the so-called ALADIN Meteogram containing the modelled meteorological elements on the surface or the lowest model level. It is visible that in the first 36 hours the model predicts cloudy weather with 8 octa of low and mid-level cloudiness. In the warm sector, the temperature is almost constant and relative humidity is close to 100 %. The post-frontal situation is characterized by significantly colder weather and the increase of mean sea level pressure of almost 20 hPa in 36 hours. Comparison with synop measurements show that the model successfully forecast most of the meteorological elements, especially the pressure change and the onset and the amount of rain. The lowest section of the Meteogram shows the wind forecast nicely reproduced by HRID post-processing visualized in Figure 5. It can be seen that the model correctly forecast the change in the wind direction, showing the passage of the front.

4. Summary and conclusions

This paper presents the selected details of high resolution isentropic diagnostic model HRID, based on polynomial hydrostatic adjustment technique, us-

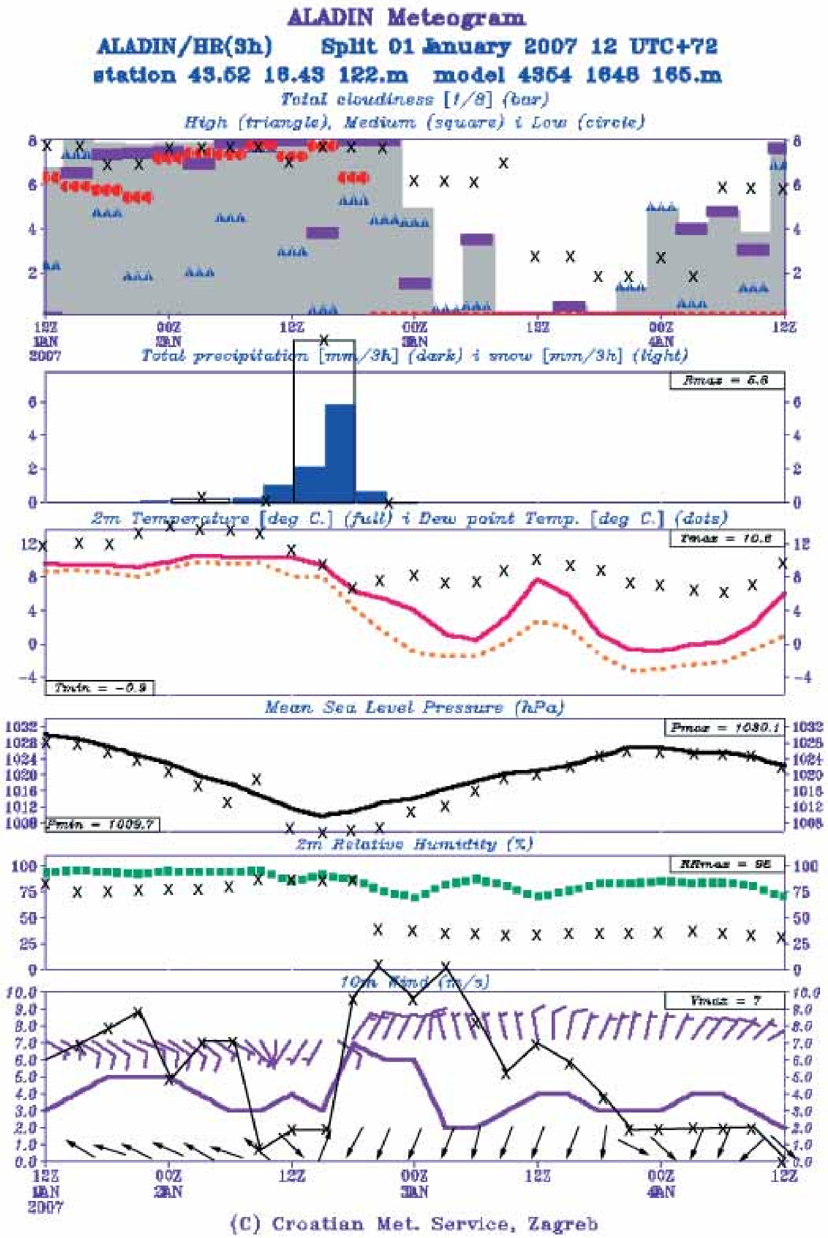

Figure 6. ALADIN Meteogram for Split, 72 hour forecast from 12 UTC analysis 1 January 2007, with total cloud cover and high, mid-level and low cloudiness (first section), total precipitation (second section), temperature and dew-point temperature (third section), MSLP (fourth section), relative humidity (fifth section) and wind direction and velocity (sixth section). Measurements from synop stations are superimposed (black crosses and arrows).

ing the reciprocal value of thermal stability parameter and its higher order derivations. In the vertical interpolation, these relations, obtained from the isentropic hydrostatic relations, are applied at local points and their infinitesimal surrounding and therefore the problem is considered analytically. This enables the elimination of finite difference approximation over the isentropic layers of various thicknesses and consequently an avoidance of their usual erors.

Although HRID is essentially a diagnostic model, the methodology for computation of vertical time cross-sections is presented as a post-processing procedure of the ALADIN prognostic model. ALADIN/HRID is hence able to provide a detailed 72 hours local forecast for any arbitrary chosen grid point with the output time step of 3 hours.

The ability of HRID is verified on the 72 hourly forecast for Split, Croatia starting from 1 January 2007 12 UTC. For a relatively common situation with frontal passage, the associated atmospheric processes responsible for particular weather changes are illustrated using designated vertical profiles. Although nowadays the model itself has the ability to predict most of the weather features, the insight into the vertical structure of the various meteorological parameters in operational forecasting is considered invaluable, especially when they are given for particular localities.

Contemporary computing abilities enable us to include more and more data into the computation. Further work should therefore imply assimilating different kinds of actual data, primarily radiosoundings in the model analysis and testing its benefits for the short range forecasting or even nowcasting. Furthermore, shorter time steps in the HRID computation are expected to contribute to the finer time scale and higher resolution of the model post-processing.

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References

Bolton, D. (1980): The computation of equivalent potential temperature, *Mon. Weather Rev.*, **108**, 1046–1053.

Brzović, N. and Glasnović, D. (1997): *Implementation of HRID at Météo France and the overview of its use in the ALADIN participating countries*, Proceedings of the third RC LACE/ALADIN workshop on the use of ALADIN products. Budapest 16–18 June 1997, RC LACE bulletin No.3, 3pp.

Bubnova, R., Hello, G., Bernard, P. and Geleyn, J.-F. (1995): Integration of the fully elastic equations cast in the hydrostatic pressure terrain following coordinate in the framework of the ARPEGE/ALADIN NWP system. *Mon. Weather Rev.*, **123**, 515–535.

Cressman, G. P. (1959): An operational objective analysis scheme. *Mon. Weather Rev.*, **877**, 367–381.

Čapka, B. (1980): Izentropska analiza ciklogeneze u zavjetrini Alpa, Magistarski rad, Sveučilište u Zagrebu.

Geleyn, J.-F. (1987): Use of a modified Richardson number for parameterizing the effect of shallow convection. In: Matsuno, Z. (Ed)., Short and medium range weather prediction, Special volume of *J. Meteorol. Soc. Jpn.*, 141–149.

Geleyn, J.-F. and Holligsworth, A. (1979): An economical analytical method for computation of the interaction between scattering and line absorption of radiation, *Contrib. Atmos. Phys.,* **52**, 1–16.

Giard, D. and Basile, E. (2000): Implementation of a New Assimilation Scheme for Soil and Surface Variables in a Global NWP Model. *Mon. Weather Rev.*, **128**, 997–1015.

Glasnović, D. (1978): *Objective cross-section analysis,* Proceedings of the XV International meeting on Alpine Meteorology, Grindelwald, September 19–25, 192–195.

Glasnović, D. (1983): *Dijagnostički izentropski model za istraživanje vertikalne strukture atmosfere.* Monografija, 1, Meteorological and Hydrological Service, Croatia, 33 pp.

Glasnović, D. (1990): Isentropic high resolution time cross-section based on polynomial hydrostatic adjustment technique. *Rasprave*, DHMZ Zagreb, **25**, 69–76.

Glasnović, D. (1996): Atmospheric static stability in respect to static energy changes. *Geofizika*, **12**, 1–13.

Glasnović, D. and Jurčec, V. (1990): Determination of upstream bora layer depth, *Meteorol. Atmos. Phys.*, **43**, 137–144.

Louis, J. F., Tiedke, M. and Geleyn, J.-F. (1982): *A short history of PBL parameterization at ECMWF*. Proceedings from the ECMWF Workshop on Planetary Boundary Layer Parameterization, 25–27 November 1981, 59–79.

Ritter, B. and Geleyn, J.-F. (1992): A comprehensive radiation scheme for numerical weather prediction models with potential applications in climate simulations. *Mon. Weather Rev*., **120**, 303–325.

Shapiro, M. A. and Hastings, J. T. (1973): Objective cross-section analysis by Hermite polynomial interpolation on isentropic surfaces, *J. Appl. Meteorol*., **12**, 753–762.

Simmons, A. J. and Burridge, D. M. (1981): An energy and angular momentum conserving vertical finite-difference scheme and hybrid vertical coordinate, *Mon. Weather Rev*., **109**, 758–766.

Whittaker, Z. M., and H. L. Petersen, 1977: Objective cross-sectional analyses incorporating thermal enhancement of the observed wind, *B. Am. Meteorol. Soc.,* **105**, 147–153.

SAŽETAK

Izentropski model visoke rezolucije primijenjen na lokalnu prognozu vremena

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Ovaj rad je najvećim dijelom posvećen diskusiji o izentropskom modelu visoke rezolucije HRID kojega je razvio Glasnović (1983) i vremenskim vertikalnim presjecima koji se koriste operativno direktnim uključivanjem u prognostički model ALADIN. HRID se zasniva na uspješnoj primjeni rutine polinomskog hidrostatičkog prilagođavanja, koja se temelji na recipročnoj vrijednosti parametra termičkog stabiliteta i njezinim derivacijama višega reda. S obzirom da se te relacije pri vertikalnoj interpolaciji primjenjuju lokalno, problem se rješava analitički i time eliminira izračun konačnih razlika u izentropskim slojevima različitih debljina. Rad prikazuje lokalnu 72-satnu prognozu za Split, pomoću vertikalnih vremenskih presjeka s detaljima vertikalne strukture atmosfere uz sve karakteristike koje prate prolazak frontalnog sustava 2. siječnja 2007.

Ključne riječi: ALADIN, HRID, objektivna analiza, vertikalni presjeci

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